Assessment and Reconstruct of Navy's Mine Impact Burial Prediction Model

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LONG-TERM GOALS

The ultimate goals are to substantially improve, quantitatively, the U.S. Navy's mine burial predictive capabilities and to provide a complete data set of mine movement in water phase and mine impact burial for model evaluation. The goals include development of a new mine impact burial model for improving Naval technical decision aids and involvement of NPS students' (U.S. Naval officers) thesis study for enhancing their combat effectiveness.

OBJECTIVES

The objectives of the project are assessment of current Navy's Impact Burial Prediction Model (IBPM), and reconstruct of IBPM using the advanced hydrodynamic theory. Both efforts are closely connected to the field experiment at Corpus Christi, Texas-Louisiana shelf sponsored by ONR IBPM program.
This effort provides guidance for field experiments such as site selection, determination of variables to be measured (e.g., ocean and sediment conditions as well as mine burial depth). On the other hand, data collected from the field experiments will be used to verify the reconstructed IBPM in a more realistic environmental scenario.

APPROACH

The approach included experimental and modeling tasks and interelated objectives identified in the section above to develop a comprehensive Mine Impact Burial Prediction Model.

(A) Experimental Approach: A series of mine drop experiments with different sizes of model mines were conducted at NPS and Naval Surface Warfare Center to obtain a complete dataset for depicting the mine movement in the water column:

Analysis on the data collected from the Mine Impact Burial Experiment (MIBEX). This experiment was designed to collect synchronous mine impact burial and environmental data. The experiment was conducted on May 23, 2000 at the site of the Monterey Inner Shelf Observatory (MISO) off of Del Monte Beach in Monterey Bay (Smith 2000). The model mine is a 55 gallon drum filled with sand to give it a uniform density. During the experiment, 17 gravity cores were obtained. The oceanic environemental paramteres were recorded at MISO. The burial depth was measured by the divers. The mine impact and environmental (water column and sediment) data were analyzed in FY01.

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14. ABSTRACT
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Mine Drop Experiment (MIDEX) at the NPS swimming pool. MIDEX basically consisted of dropping each of three right cylinders into the water where each drop was recorded underwater from two viewpoints. The controlled parameters for each drop were: center of mass position (COM), initial velocity (V_{init}), drop angle and the ratio of mine's length to diameter. Figure 1 depicts the overall setup.

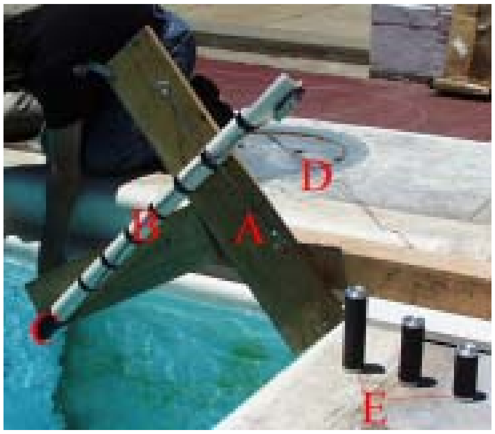

Figure 1. Equipment used. A denotes drop angle device, B mine injector, C infrared light sensor, D output to universal counter, E mine shapes.

Three mine shapes were used for the experiment. All had a circular diameter of 4 cm, however the lengths were 15, 12 and 9 cm respectively. The bodies were constructed of rigid plastic with aluminum-capped ends. Inside each was a threaded bolt, running lengthwise across the mine, and an internal weight (Fig 2). The internal weight was used to vary the mine's COM and could be adjusted fore or aft.

Figure 2. Internal Components of Mine Shape

COM positions were denoted using 2, 1, 0, -1, -2. COM 0 cases were identical to the IMPACT 25 model's uniform density assumption (COM = CB). All other cases indicated the relative position of the COM to the CB.

Initial velocity was calculated by using the voltage return of an infrared photo detector located at the base of the mine injector. The infrared sensor produced a square wave pulse when no light was detected due to blockage caused by the mine's passage. The length of the square wave pulse was converted into time by using a universal counter. Dividing the mine's length by the universal counter's time yielded V_{init}. The mines were dropped from several positions within the injector mechanism in order to produce a range of V_{init}.

Drop angle was controlled using the drop angle device. Five screw positions marked the 15, 30, 45, 60, and 75-degree positions. The drop angles were determined from the lay of the pool walkway, which was assumed to be parallel to the water's surface. Two 10 cm grids were affixed to each pool wall. These grids were constructed out of fiberglass and were used to record the mine's position in the x, -z and -y, -z planes (fig 3). For each drop the mines were set to a COM position. For positive COM cases, the mines were placed into the injector so that the COM was located below the center of buoyancy. For negative cases, the COM was located above the center of buoyancy prior to release. Each video camera had a film time of approximately one hour. At the end of the day, the tapes were replayed in order to determine clarity and optimum camera position.

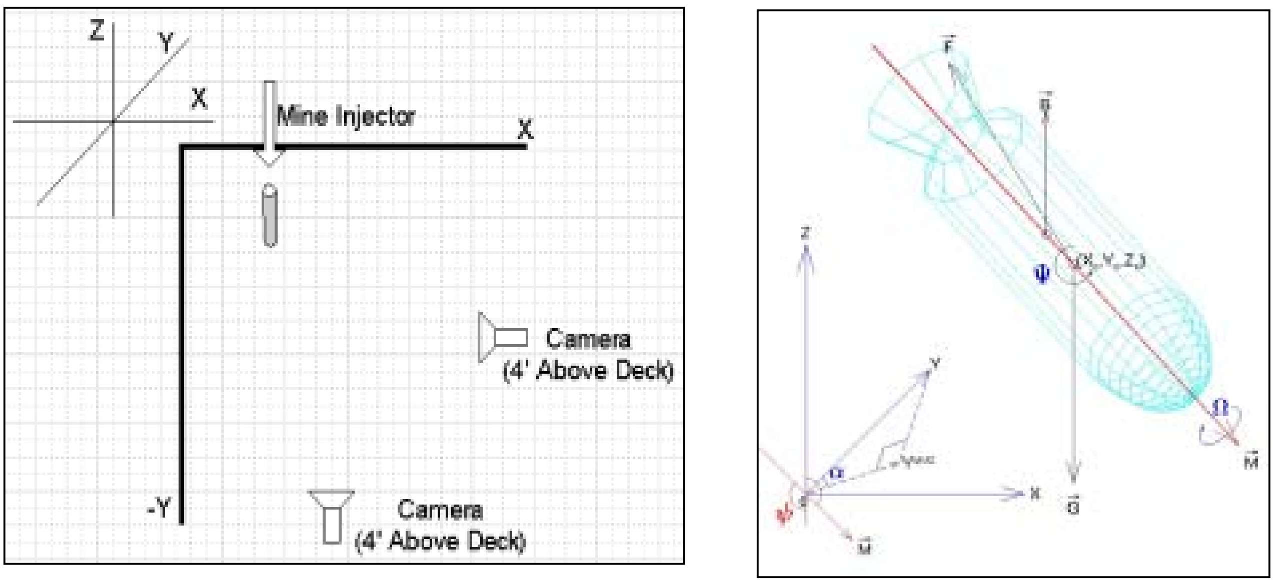

Figure 3. Earth and mine coordinate systems.

Participation of Hydrodynamic Testing of Cylindrical Mine Shape (1/3 scale) at Carderock. The experiment was led by Drs. Phil Valent and Mike Richardson at NRL on September 12-14, 2001. Peter Chu and his student (LCDR Ashely Evans) participated the experiment including design and data collection. LCDR Evans will analyze the data for the the planned mine impact burial prediction field experiment.

(B) Modeling Approach: Most important step toward building a realistic IBPM is to lift the assumption of mine mass uniformity used in IMPACT25. With a non-uniform mass distribution, the gravity center (depending on individual mine) and the buoyancy center (depending mine shape) are not co-located. The new IBPM model should have moment of momentum balance,

$$[\mathbf{r} \times (d\mathbf{V}/dt)]\, dm = \mathbf{M}_{w,a} + \mathbf{M}_b + \mathbf{M}_d$$

We develop a new hydrodynamic model for mine movement in the water column on the base of the full physics (balance of momentum, and balance of moment of momentum).

WORK COMPLETED

A synchronized data set of ocean environment (including waves, currents, and bottom shear strength, …) and mine burial depth was established on the base of the Mine Impact Burial Experiment (MIBEX). A technical report depicting this dataset was published by NPS and widely distributed into the minewarfare community.

Mine Drop Experiment (MIDEX) was conducted in June 2001 at the NPS swimming pool with 1/20 scale model mines. Around 500 mine drops were completed with different mine parameters (L/D, COM) and drop conditions (angle and velocity). Upon completion of the drop phase, the video from each camera was converted to digital format and a dataset for mine movement in the water column was established.

Mine test experiment at Carderock was completed. LCDR Ashely Evans participated the experiment and started the data analysis.

The hydrodynamic system depicting the movement of rigid body (such as mine) in the water column has been established on the base of balance of momentum and moment of momentum. This system consists of nine nonlinear equations. Among them, three equations depict the acceleration of the center of mass; three equations depict the moment of momentum balance, and three equations predict the three Euler angles of the mine. This hydrodynamic system does not have analytical solutions due to the nonlinearity. We are building a numerical model to solve the problem.

Workshop was conducted on ONR Expert System Program on Mine Impact Burial Prediction at NPS on January 10, 2001. The MIBEX dataset was transferred to the ONR Expert System group.

RESULTS

After analyzing the MIBEX ocean environmental and model mine burial depth, and comparing the observed and predicted (by IMPACT25) mine burial depths, we concluded that **IMPACT over-predicts the burial depth.**

MIDEX in June 2001 shows the existence of six different mine trajectory patterns (Table 1). **Mine rotation around its center of gravity used in IMPACT25 was never observed**.

Table 1. Description of Mine Coordinate Based Trajectory Patterns

Mine Trajectory Pattern	Description
Vertical	Mine exhibited little angular change about z-axis.
Spiral	Mine experienced rotation about z-axis.
Flip	Initial water entry point rotated at least 180° during mine motion.
Flat	Mine's angle with vertical near 90° for most of the trajectory.
See-Saw	Similar to the flat pattern except that mine's angle with vertical would oscillate between greater (less) than 90° and less (greater) than 90° - like a see-saw.
Combination	Complex trajectory where mine exhibited several of the above patterns.

Hydrodynamic model of mine movement in the water column has been developed. This model contains nine nonlinear equations for momentum balance (three equations), moment of momentum balance (three equations), and Euler angles of the mine (three equations).

Statistical mine impact prediction model was established from the MIDEX. The 3-D data collected at MIDEX were nondimensionalized. Multiple linear regression analysis was performed to establish relationships between the mine input parameters including COM and L/D (mine parameters) and drop angle and initial velocity V_{init} (dropping parameters); and the output variables; (x_m, y_m), (u,v,w) and ψ_1 (table 2):

$$f_i = \beta_0 + \beta_1 \cos(\text{drop angle}) + \beta_2 \, L/D + \beta_3 V_{init} + \beta_4 \, COM$$

The results indicate that COM position has the largest influence on all output variables.

Table 2. Multiple Linear Regression Analysis Correlation Coefficients.

	x_m	y_m	ψ_1	u	v	w
β_0	-.0746	-.0546	102.5691	.0040	-.0135	-.9481
β_1	.1190	-.0828	-13.3508	-.0075	-.0106	-.1080
β_2	-.0469	-.0798	-.5009	-.0011	.0005	.0295
β_3	.0372	.0622	1.0437	.0025	.0011	-.0221
β_4	.2369	.4330	472.2135	-.0090	.0537	-1.2467

IMPACT/APPLICATIONS

• The dynamic system (nine nonlinear equations) for the mine movement has the potential impact on the nonlinear dynamics. The hydrodynamics of mine impact in water column can be applied to a general scientific problem of the fluid-rigid body interaction including stability and chaotic motion.

• The datasets obtained from three consecutive experiments, MIBEX, MIDEX, and Mine testing at Carderock, will impact the scientific and Naval mine warfare communities on the mine movement in the water column.

TRANSITIONS

• The results obtained from this project are transferred to the Naval Oceanographic Office, COMINEWARCOM, and the ONR Mine Impact Burial Prediction group.

• Two major weaknesses in water phase of IMPACT25 (tumbling of mine and no moment of momentum balance) are well accepted by the mine warfare community.

• The datasets collected from MIBEX and MIDEX will greatly impact on the development of an accurate Mine Impact Burial Prediction Model.

• The data were also used for development of the Expert System for Mine Impact Burial at the Applied Physics Laboratory of the John Hopkins University and the Environmental Sciences Department of the University of Virginia.

RELATED PROJECTS

This project is related to the ONR Expert System program. The results obtained from this project are the basic materials for building the Expert System for mine burial prediction.

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PATENTS

None